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ROADS AND PAVEMENTS

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The benefits of education and of useful knowledge, generally diffused through a community, are essential to the preservation of a free government.

Sam Houston

Cultivated mind is the guardian genius of democracy. . . . It is the only dictator that freemen acknowledge and the only security that freemen desire.

Mirabeau B. Lamar

INTRODUCTION

On February 13-15, 1917, a meeting was held at the University of Texas, under the auspices of the Engineering Department, for all engineers interested in municipal work. There is at present no organization of civil engineers in Texas which devotes any considerable part of its time to city engineering problems. This meeting was held because it was thought that there was a real need for an organization in this line of work, and the response from engineers over the state was very gratifying. It is intended that a similar meeting shall be held at the University of Texas each year, and all city engineers, their assistants, and others interested in road construction, sanitary design and construction, and the various other branches of municipal work, are most cordially invited to attend. Engineers are also invited and urged to present papers or discussions on any line of municipal engineering upon which they have been engaged or in which they are particularly interested. Requests for papers on particular lines of work, if sent in early enough, will be turned over to experts engaged in the line of work desired, and their discussion invited.

Ample time will be given to discussion of papers presented, as there is probably greater benefit derived therefrom for the indivdual members than from the reading of the papers themselves.

Some little confusion, due to class schedules, was noticeable during the meeting, but arrangements in this respect will be perfected. The following papers on various subjects connected with roads and pavements were presented at the February meeting, and are issued here in bulletin form for the advantage of those who could not make arrangements to attend.

R. G. T.

CONTENTS

CONCRETE ROADS: CONSTRUCTION AND MAINTENANCE

By A. W. Bowles, Texas Portland Cement Association

[*Synopsis:* A discussion in detail of the problems entering into the design, construction, and maintenance of concrete road surfaces. Necessity for proper drainage, factors determining thickness, proportions, and crown of road surface, each step in the construction of the pavement, and the methods of patching defective pavement, together with other maintenance problems, taken up, showing the latest practice in each field.]

Mr. Chairman and Gentlemen: It was with somewhat of a shock, on starting this paper, which is to cover *Concrete Roads: Construction and Maintenance,* that I realized I had been assigned a subject which, when discussed at the last National Conference on Concrete Road Building, was carefully covered by more than seventeen committees made up of engineers and others of national ability and reputation. However, I appreciate and wish to thank Mr. Taylor, who arranged this program, for the opportunity of helping to this little extent to further the practice of permanent highway construction.

The subject as assigned may rightfully be divided into two distinct and independent headings:

I. The Construction of Concrete Roads.

II. The Maintenance of Concrete Roads.

I. The Construction of Concrete Roads

Considering the construction of any highway, whether it is a system or not, the engineer first views his problem in a broad sense, and I believe the construction of concrete roads should be approached in just such a manner. To accomplish this end, I have subdivided the first heading as follows:

1. Design.
2. Construction.

1. *Design.*

The problem of the design of a concrete roadway resolves itself into the drawing up of plans and specifications to fit local problems and conditions, which exist in each and every case. It is too often the case that the engineer selects the first copy of specifications at hand, which more than likely have been prepared for circulation over the entire country, and which for this reason can not possibly fit local conditions.

In drawing up plans and specifications for a concrete road, street or alley, the engineer should consider the following:

(a) Materials.
(b) Grading.
(c) Drainage.
(d) Subgrade and sub-base.
(e) Forms.
(f) Pavement section.
(g) Joints.
(h) Measuring materials and mixing concrete.
(i) Reinforcing.
(j) Placing and finishing concrete.
(k) Protection of curing.
(l) Shoulders.

All these items should be covered in the specifications, which should be carefully written by the engineer to cover any condition which exists in the specific instance.

Considerable trouble and expense may result from the adoption of standard specifications verbatim. Extreme difficulty may be experienced in obtaining materials to comply with the specifications, when some slight change would allow the use of local material and still obtain excellent results.

(a) *Materials or Aggregates for Concrete Roads.*

The fact that the finished surface must withstand three destructive agencies, traffic, weather, and structural stresses, makes it necessary that the very best materials be used. It is hard to distinguish between the effects of traffic and weather.

Experience has proven that the life of a concrete roadway,

in the face of these destructive agencies, depends upon the qualities of the aggregates. These qualities are:

(1) Durability of the particles.

(2) Grading of these materials.

(3) Cleanness of these materials.

(4) Chemical and mineralogical composition of the materials.

Aggregates for this type of construction are of two sizes:

Coarse aggregate, which by practical experience should range in size from ¼ inch to 1½ inches.

Fine aggregate, graded in size from ¼ inch down, with a limited amount of the finest particles.

Materials used successfully as coarse aggregates are:

Crushed rock (hard limestone has given best results).

Gravel or crushed gravel.

Slag.

As fine aggregates:

Natural bank sand and rock screenings, but from a construction standpoint it is advisable when using screenings to specify half sand, which will give a much easier finished concrete.

Generally, materials of such quality must be chosen and the proportions so made that uniform wearing will result. Local conditions in this regard lead to the adoption by the engineer of either the one or two course type of pavement.

Grading of these materials should be such that construction will not be hampered and the densest and most durable concrete will result.

To serve satisfactorily as aggregates in this construction, all materials must be practically free from clay, loam, mica, or other materials which have proved detrimental in concrete. Not only the amount but the way in which this foreign matter occurs proves the controlling factor. Coating around the aggregates, even in small percentages, may prove detrimental to the bond, and should be considered. It has been proved by practice that pit-run or crusher-run materials can not be used satisfactorily in this type of construction.

The chemical and mineralogical composition of the aggregates quite often affects the wearing quality of the finished roadway. One can readily realize that the structure of the aggregates

affects the road surface in so far as its resistance to wear and weather.

These conditions call for a careful study of the aggregates available prior to drawing up the specifications, to insure that only the most adaptable for this type of construction be used.

(b) *Grading.*

Grading is similar to that in other types of road work. More care should be exercised, in order to obtain as compact a grade as is possible on which to construct a monolithic surface.

(c) *Drainage.*

The drainage problems in any highway construction may be divided into three classes: (1) Disposal of surface water. (2) Disposal of rainfall on the road itself. (3) Underground drainage.

The first two problems are handled by the construction of side ditches, with a suitable crown to the road surface to insure drainage from the surface.

In communities where excessive climatic conditions are experienced and the ground freezes to some extent, it is very important that moisture be drained off to a level considerably below the base of the concrete.

We believe this is also true in soils which have a tendency to swell and shrink with an increase or decrease in moisture content. Both frost action in the sub-base and the movement with swelling and shrinking will cause heaving and settlement and subsequent cracking of the monolithic surface.

Underground drainage has been accomplished in two different ways: First, by raising the roadway; and, second, by installing a system of sub-surface drainage.

Engineers in this section up to the present time have met the drainage problem by the construction of fills and side ditches to care for all surface water. This has one disadvantage, and one especially bad in the black-land section of this state, in that the fills constructed to a depth of two feet or more show considerable settlement for at least six months to a year after construction. This makes it dangerous to construct hard and monolithic surface roads on them.

(d) *Subgrade and Sub-base.*

Subgrades for a concrete roadway are built on three cross sections, all three of which have their advocates and good points, and are used in either one place or another.

(1) Crowned subgrade (either parallel to the road surface or less than the crown of the road).

(2) Flat subgrade.

(3) Dished subgrade.

Crowned subgrades are advocated for all pavements more than 20 feet in width, necessitating the construction of a greater thickness of concrete at the center than at the sides.

Dished subgrades are used universally in the construction of concrete alleys, and to some extent for roadways. This type diminishes the tensile stresses thrown in the concrete.

The preparation of either type consists in grading, leveling, and rolling, to insure a firm and unyielding base or foundation.

(e) *Forms.*

The specifications should be drawn to insure a straight line and uniform grade. If a large amount of work is contemplated under the specifications, it appears advisable to specify the use of steel or steel-capped forms.

(f) *Pavement Section (Widths and Thickness).*

Traffic conditions determine the width of any roadway, and a careful and thorough traffic census and a considerable study into the probable growth of the community should be made before either

The single track (8 to 10 feet wide),

The double track (14 to 18 feet wide), or

A wider roadway (22 to 30 feet) is decided upon.

There seems to be a considerable field for the single track road throughout this section, especially where adequate shoulders are constructed. The narrow hard surface will carry the larger percentage of the heavy loaded traffic, and shoulders

constructed under these conditions will stand for a considerable length of time.

The proper thickness depends more or less upon

Climate,
Width of slab,
Type of pavement (whether reinforced or not),
Character of soil,
Thoroughness of surface and subdrainage,
Degree of consolidation of subgrade,
Proportions and quality of concrete,
Character of workmanship,
Care in curing,
Character of traffic.

Of course, these factors are not of equal importance, and their importance depends upon the locality.

The thickness of the slab for this reason can best be determined by a study of the practice throughout the country on successful and unsuccessful work. A short summary of these may prove of interest.

(1) *California:* Semi-arid and arid climate. A four-inch thickness has been used with success.

(2) *Oregon.* Semi-arid. Five and one-half inches to 6½ inches seems most successful.

(3) *Mississippi Valley:* Six inches at the sides and 7 inches to 8 inches at the center.

(4) *New York:* Six inches at the sides and 8 inches at the center is recommended after trying many experiments.

(5) *Texas:* Four inches to 6 inches at the sides and 6 inches to 8 inches at the center is recommended throughout the central section of the state.

There seems to be a distinction between practice for country roadways and city streets with respect to the recommended crown. One twenty-fourth to 1/200 of the width has proven sufficient for country roadway, while 1/50 to 1/200 is satisfactory to insure against water and rubbish remaining on the surface of city streets.

It is an advantage that, with the slight crown necessary on a concrete road, the tendency to distribute traffic over the en-

tire surface is increased and the wear on the surface distributed so that the life of the roadway is prolonged. A similar advantage can be cited for city streets.

I might mention the matter of limiting grades on which a concrete road or pavement would be serviceable. The limiting grade is dependent to a great extent on climatic conditions, the character of traffic, and the finish of the surface.

In humid climates, frost or ice may limit the grade to 7 and 8 per cent, while in arid climates up to 10 and 12 per cent will in most cases prove satisfactory for all types of traffic.

(g) *Joints.*

To quote from the report of the committee on expansion and contraction in concrete roads, which condition causes transverse and to some extent longitudinal cracking of the road surface, the following conclusions may reasonably be drawn from the foregoing:

"That contraction and expansion are caused both by temperature changes and by changes in moisture conditions, and that under climatic conditions similar to those at Washington, D. C., the effects from these two factors in concrete road surfaces are approximately of the same magnitude.

"That in concrete roads, contraction and expansion are sufficient to cause frequent transverse cracks, unless joints are provided. That the actual movement in any particular case depends upon the character of the concrete and of the subgrade. A sloppy concrete shows greater movement than a concrete mixed only moderately wet. No more water should be used than is necessary to permit of convenient placing and forming."

Practice has proven that joints placed in concrete roads at the time of construction will diminish the maintenance expense necessary. It is at present the recommended practice that joints, to be of maximum effect, should be spaced as follows: Roads, 25 to 50 foot spacing, varying directly with the width, except where reinforcing is used, where a 50 foot spacing is allowable.

Streets, where wider sections are used: Twenty-five foot spacing is recommended.

The specified thickness of the filler necessary is greater in

unreinforced roads, where a ¼ inch filler is recommended, than in reinforced roads, where ⅛ inch filler is sufficient.

Two types of joints have been successful: the protected and the non-protected joint. Engineers differ in regard to the advisability of protecting the edges of the concrete adjacent to the filler with steel plates. The unprotected joint as used today is made by installing at the time of construction the specified thickness of prepared fiber matrix ½ to 1 inch wider than the thickness of the concrete.

(h) *Measuring Materials and Mixing Concrete.*

Fairness to the contractor demands that we cover completely in the specifications the details which he is expected to follow while measuring and mixing concrete.

The proportions of cement, sand, and stone for concrete roads are dependent upon the class of materials and upon the type of pavement to be laid, whether one or two course.

The one course type of pavement is to be recommended where materials satisfactory for its construction are to be found. However, material conditions may make it economical to adopt the two course pavement, which becomes the case where a local material suitable for a concrete base, but not satisfactory from a wearing surface standpoint, is to be had at low cost.

In such a case a sufficient quanity of hard, suitable stone can be shipped in to construct the wearing course.

The recommended proportions and thickness for one course and two course roads and pavements are:

One Course:

Six inches thick, of the proportions one part cement, two parts sand, and three parts stone.

Two Course:

Base, 5 inches thick, of the proportions one part cement, two and one-half parts sand, and five parts stone.

Top, 2 inches thick, of the proportions one part cement, one and one-half parts sand, and two and one-half parts stone.

However, these proportions should be determined only after careful and scientific study of the aggregates, and in numerous cases may be changed from the proportions mentioned above.

In order to obtain a uniform wearing surface, we must have uniform proportioning of materials, and to accomplish this the use of measuring boxes is recommended. The use of these should in no way hamper the progress of the work.

Engineers are universally agreed that satisfactory results can only be obtained by the use of a batch mixer. It is advisable to specify the duration of mixing, and practice has demonstrated that stronger and more durable concrete will result if a minute to a minute and a half mix is specified, with the minimum number of revolutions of the mixer specified.

It is further to be recommended that a method of delivery be specified which will make the use of horse drawn or push carts expensive and impracticable.

(i) *Reinforcing.*

Reinforcing is advisable for three reasons: to care for heaving (due to frost action or alternate wetting and drying of the subbase); to bridge over soft spots or settlements in the base; to resist the shrinkage of the pavement (due to moisture content or temperature changes).

The use of reinforcing will decrease the number of joints necessary, which have proven the greatest disadvantage to concrete roads, and will also reduce to a minimum the maintenance cost.

Reinforcing should be placed three inches below the finished surface, and the amount should vary with the width as follows:

Width of Road	Reinforcing per Foot Length	Reinforcing per Foot Width
16 feet	0.090 sq. in.	0.030 sq. in.
20 "	0.100 "	0.030 "
30 "	0.120 "	0.030 "

(j) *Placing and Finishing Concrete.*

The methods of placing and finishing concrete have been determined by practice, and should be covered in the specifications to guarantee satisfactory work. Methods should be used to allow finishing of the roadway with as little handling and working of the concrete as is possible after leaving the mixer.

Finishing should be accomplished with a wood float just prior to the time of initial set, which will relieve surface tension and diminish surface checking.

(k) *Protection of Curing.*

Protection of the concrete from the sun's heat in summer and also from dry winds is necessary to allow complete satisfactory setting and to eliminate drying out of the surface. Protection by canvas coverings should be specified when necessary.

When sufficiently hardened, concrete should be covered with dirt 2 to 3 inches thick, and kept wet for a period of ten days to two weeks.

(l) *Shoulders.*

Shoulder work is of great importance on single track roadway, where it will be called upon to withstand wear and traffic. Shoulders for single track roads should be constructed of either gravel or crushed rock of sufficient width to allow the passage of two teams. Shoulders for other widths of roadway should be constructed of suitable material and of such cross section to guarantee satisfactory surface drainage.

In this discussion I hope I have brought out the important facts which should be covered in the specifications, and that I have made it clear why each should be considered separately, due consideration being given to both local conditions and the experience on similar work throughout the country.

2. *Construction.*

The construction of a concrete roadway is most easily discussed as a general subject, describing briefly the modern methods followed. However, a division can conveniently be made.

(1) Drainage and preparation of subgrade.

(2) Handling of materials:

  (a) Sand and stone.

  (b) Cement.

  (c) Water.

(3) Forms: handling and placing:
 (a) Setting.
 (b) Removing and curing.
(4) Mixing, placing, and finishing:
 (a) Organization of crews.
 (b) Construction:
  (1) Handling materials.
  (2) Concreting.
  (3) Finishing.
  (4) Curing.
  (5) Shoulder construction.
(5) Engineering and inspection.

(1) *Drainage and Preparation of Subgrade.*

For streets, as well as roads, tile drains may be used. These should be laid on each side of the roadway, or may be laid on one side only, with cross drains leading thereto at a suitable depth, depending on the width of the pavement. Drainage trenches, if placed under the subgrade, should be completed before final rolling.

Grading

When roadways are constructed over fills, extreme care should be observed to insure the use of proper materials, in layers of such thickness that the fill may be thoroughly compacted with minimum settlement. In general, fills shall be made in thin layers; the fills should be allowed to stand as long as possible. Deep fills should be allowed to settle through one winter, if such procedure is possible. Wetting and rolling should always be resorted to.

The subgrade should be of uniform density, so that it will settle evenly. An old roadbed should be scarified, reshaped, and rolled. All subgrades adjacent to the curb should be hand tamped. The sub-base should be wet prior to laying concrete.

(2) *Handling of Materials.*

Four methods of handling materials are used, the economy of each depending upon the locality and the length of the haul:

First, wagon and team haul; second, auto trucking; third, traction engine and trailers; fourth, industrial railroads.

The controlling essential is that the method of hauling shall provide sufficient material to allow uninterrupted movement of the construction gang at the mixer.

Team and auto haul are adaptable to conditions where good roads already prevail. The economy of this method is questionable where more than a two-mile haul is experienced.

Industrial railways are adaptable where long stretches are to be built, with an average haul of more than two miles. This method allows easy distribution of materials.

In sorting materials, it has proven economical, where the use of a traction type of mixer is adopted, to deposit the materials in piles along the prepared subgrade. This method is to be encouraged. Methods necessitating the use of horse-drawn or hand-pushed carts are to be condemned, since it leads to interruption of the work, cutting up of the subgrade, and the segregation of aggregates in the concrete. Sufficient material should be spotted on any job to allow the mixing and placing to continue a considerable period of time, as weather conditions may make hauling impossible when construction could continue.

In the handling of cement, such arrangements must be made to protect it from the elements. Where a traction type of mixer is used, cement must be spotted at intervals of not more than 50 to 100 feet. To protect these piles, it is customary to erect small canvas houses or tents. These are easily moved forward as the cement is used. Cement should always be piled on platforms, raised from two to six inches above the ground.

The water supply, in many instances, becomes a serious problem for engineers and contractors. In both city and county work, this should be handled by the construction of a pipe line running parallel to the road or street and back two to four feet from the edge. T's should be placed with control cocks at intervals of every 100 to 200 feet. The supply is easily carried to the mixer by a hose line, and also easily supplied for curing in a similar manner.

(3) *Forms.*

Forms should be handled in such manner as will reduce the

expense connected with this item as much as possible. This calls for the adoption of a type of form which will reduce the repair and replace item as much as possible.

For a large amount of roadwork, which calls for considerable handling of the forms, the use of steel forms will prove most economical. Two by six wood steel capped forms will also prove satisfactory. The steel capping should extend over one end of the 2x6, to faciliatate placing the form on line and grade.

Separate gangs should be organized for setting and removing and cleaning forms. All forms should be cleaned when removed, and steel forms should be oiled at such intervals of time as to insure against excessive depreciation. Wooden forms should be piled flat, to prevent warping.

Two men are sufficient to set forms sufficiently in advance for concreting gangs. The curing gang may satisfactorily be used in removing and cleaning the forms.

(4) *Mixing, Placing, and Finishing.*

The organization of a concreting crew should take into account the size and type of the mixer and also the type of the work to be done, whether street or road work. For county roadwork, with a two-sack batch capacity mixer and standard specifications, 26 men can be used satisfactorily on the construction.

2 men handling cement.	2 men leveling concrete.
2 men wheeling sand.	2 men on template.
2 men loading sand.	1 finisher.
3 men wheeling stone.	3 men curing.
3 men shoveling stone.	1 engineer.
1 man at mixer.	1 fireman.
2 men grading subgrade.	1 foreman.

The organization of the crew should be worked out carefully and be such that the maximum capacity of the mixer will be obtained, allowing the specified time for mixing.

In construction, it will be found economical to use loaders separate from wheelers. With this arrangement, the use of

measuring boxes, to obtain accurate proportions, will not prove any drawback to the progress of the work.

The size of the crew necessary for the proper distribution of concrete depends upon the type of delivery connected with the mixer. With boom and bucket or chute mixer, one man is needed to handle the chute and two for distributing the concrete.

Finishing

The finishing gang in concrete road construction consists of two men handling the template, or strike-board, and the number necessary properly to float and finish the work. The strike-board should be constructed of such length and dimensions as can be easily handled. On roadways 20 feet and less in width 3 in. by 10 in. stock is usually used; for the narrower widths, two 2x10's are usually bolted together and crowned as specified for the crown of the road.

The concrete, after being leveled off to approximate grade, should be struck off with a template, or strike-board. Finishing should be done after the surface water has drained off.

A number of methods of finishing are in use.

(1) By floating with long handled floats from the side of the roadway.

(2) By hand floats from bridge, no part of which touches the surface.

(3) By the use of leather, canvas, or wood strips.

The last two methods are to be recommended, the strip being cheaper and easier to handle. It is, however, necessary to use the hand float from a bridge to work out rough and uneven spots in the surface where the strip method is adopted.

Curing

In hot, dry weather, canvas protection should be given the surface after finishing and until it is sufficiently set to allow sprinkling and subsequent covering with sand, dirt, or loam of such character as will hold moisture. This should remain wet for a period of ten days or two weeks, depending on weather

conditions, and should not be opened to traffic until allowed subsequently to dry out.

Other methods of curing should be adopted when weather conditions demand. Where a uniform temperature under 60° and above 34° exists, the surface need not be covered, but it is advisable to sprinkle when the temperature rises.

When a freezing temperature is experienced, arrangements should be made to protect the concrete from freezing. It is advisable to discontinue concreting if a freezing temperature is to be encountered.

Shoulders

The shoulders should be constructed after the surface has been cured and prior to opening the road to traffic. The shoulders should be placed and rolled, care being taken to keep the roller off the edge of the concrete.

(5) *Engineering and Inspection.*

Engineering and inspection connected with the construction should be planned to obtain uniform work in accordance with the specifications. All sub-base should be checked by the engineer in charge before materals are spotted, and all materials should be accepted before hauling on the work.

It should be the duty of the inspector to check up the materials, including the cement, on every section, and to watch carefully the time of mix used at all times throughout the work.

II. The Maintenance of Concrete Roads

Concrete roads, like all other types of pavement, if they are to give their maximum service, must be properly maintained. The small amount of work and small expense necessary to maintain a well built concrete road in perfect repair should not be made an excuse for delaying the work, but rather an incentive to have it done immediately.

Maintenance should be systematic, and imperfections given immediate attention.

Cracks.—Cracks in concrete roads occasion no inconvenience whatever to traffic, and traffic will not injure the road at

such a place if the crack is filled with tar and covered with sand. The crack should be first cleaned with a stiff wire broom, and all loose particles of material removed. If the crack is too narrow to permit cleaning in this manner, it may be cleaned with an air jet from an automobile pump. Tar should then be poured into the crack in sufficient quantity just to flush over the edges, and afterwards covered with coarse dry sand.

Tar.—Refined coal tar should be used, having a melting point (half inch cube method in water) of about 100 degrees Fahrenheit. The tar should be heated from 225 to 250 degrees Fahrenheit at the time of application, and may be applied by means of a sprinkling can, with spray nozzle removed. Sand or screenings, thoroughly dried, graded from ⅛ to ¼ inch, should be spread over the surface before the tar has cooled.

Small Holes.—Where a small hole occurs, due to the displacement of a lump of clay or a piece of coal or wood, it should be thoroughly cleaned, and filled with tar and stone chips. If the hole is 2 or 3 inches in size, it should first be wiped with the tar, and stone chips put in; these are covered with more tar and sand, and tamped into place.

Slight Depressions.—If, for any cause, the surface of the concrete has scaled and a slight depression formed, it can be coated with tar, stone chips added, these in turn covered with tar, and the whole covered with sand and tamped into place.

Deep Holes.—If, through neglect or other causes, a hole of any considerable size and depth has formed in the surface of a concrete road, the concrete surrounding the edge should be cut away until the walls are made practically vertical, and cut to a depth of at least 3 inches, or as much deeper as the hole may be. The hole should then be filled with water, and stand for a few hours, after which the water should be removed, the sides washed with cement paste, and the hole filled with concrete of as nearly the same materials and mixture as that in the original road. The surface should be finished with a wood float, and brought to a true shape with the surrounding surface of the concrete, then covered so as to protect it from traffic. This may be done by the use of steel plates or pieces of plank, which should in turn be covered with moist earth or

gravel. This will permit the traffic to use the repaired portion of the road without injuring the concrete. On a wide street, where there is sufficient room, a barrel could be placed over the hole and traffic diverted around it.

If it is necessary to cut a hole through the entire thickness of the concrete slab, gravel should be placed in the sub-base and thoroughly rammed, so as to form a compacted base on which the new concrete will rest. Where water has been allowed to stand in such a place, it should be compacted after the water has been removed and just before laying the concrete.

The consistency of the concrete should be sufficiently stiff to require considerable tamping to bring water to the surface, so that it may be possible to ram it thoroughly into place.

A new patch should be kept moist for at least 4 or 5 days, and protected from traffic at least 10 days.

Conclusion

Owing to the increase of population, the travel upon rural and suburban roads and city streets has increased rapidly in recent years; and this increase in travel, together with the introduction of the automobile, has necessitated the development of a new type of road surface.

The concrete road is admirably adapted to meet present-day traffic conditions. Concrete roads are moderate in first cost, low in maintenance, smooth, hard, dustless, sanitary, easily cleaned, and not slippery. They are suitable, first, for country highways, for roads subjected to overflow, on hills where the macadam road surface may be washed away more rapidly than worn away; and, second, for pavements in small cities, for outlying streets of larger cities, and especially for all streets where curbs are not required.

ASPHALTS AND TARS IN SURFACE TREATMENT

By R. G. Tyler, Adjunct Professor of Highway and Sanitary Engineering, University of Texas

[*Synopsis:* A discussion of the use of asphalts and tars in surface applications on earth, gravel, macadam, and concrete roads surfaces. With earth roads, this treatment only to be considered as a maintenance proposition. Waterproofs and settles the dust. Gravel not so satisfactory a foundation for this surface mat as macadam. On gravel, satisfactory as maintenance proposition. On macadam, good permanent construction. Advantages and disadvantages of asphalt and refined tars discussed. Thin surface treatment on concrete roads described. California practice discussed.]

During the last few years, the use of asphalt and tars in surface treatments of roads constructed of various materials has received considerable study, and has had the attention of investigators and experimenters in various parts of this country.

California has led in this phase of bituminous construction, due to the abundant, and therefore cheaper, supply of asphalt and an ideal climate, from the road-builder's standpoint. Bituminous treatments have been given practically every type of road, with varying degrees of success. For convenience, in this paper, the bituminous materials used will be discussed under the headings of the type of road treated, i. e., treatment for earth roads, treatment for gravel and macadam roads, and treatment for concrete pavements.

Treatment for Earth Roads

From time to time, the opinion has been advanced that bitumen as a binder was a panacea for all ills, that it could be mixed in proper proportions with any material whatever, and used to make a durable road surface. So types of pavement were developed whereby earth was mixed with bituminous material, and shaped into a road surface. This has not been successful, however, and experience has shown that permanent construction can not be obtained by the use of asphalts or tars on earth roads. The reason for this is readily apparent. The

bitumen is a binder, and, to form a satisfactory road surface, it must bond together a material that has distinctive wearing qualities. This quality is lacking in ordinary soil, and a road surface built of these materials will not have the requisite stability. It should be remembered, therefore, that the use of oils on earth roads, whether mixed or applied as a surface treatment only, is a maintenance proposition strictly. The proper use of a suitable material will, however, serve as a dust palliative, and will also form an impervious surface, which will prevent the road cutting up into mud, except in periods of prolonged rains.

A street carrying heavy traffic should not be oiled, as oiled earth road surfaces have not the necessary stability to carry heavy traffic. But, on many of the streets in the residential sections of a city, oiling is a justifiable procedure. A proper treatment with oil will render these streets practically dustless, and make them so they can be used at all times throughout the year.

Athough so much has been written and said on the method of preparing street surfaces for treatment, the importance of so doing can not be over emphasized, and a few words here will not be amiss.

The street should be graded and brought to the proper cross-section. The drainage must be taken care of, as oiling will not improve a mudhole, and a poorly drained street may be worse after oiling than before. It is necessary also that the surface to be treated be free from dust, or the oil will not penetrate into the surface. To insure this condition of freedom of dust, it is well to give the road a light sprinkling immediately before the oil is applied. Care should be taken not to use too much water on the road, as too much is as objectionable as the dust.

The oil is then applied, either by hand or preferably from a pressure distributor, at a rate of from ¼ to ½ gallon per square yard. The first time the road is oiled, ½ gallon will probably be needed, but for subsequent treatments ¼ gallon per square yard will suffice. Only so much oil should be used as the road will readily take up, as, if more than this amount is used, it

will run off the street and be wasted, or will stand in puddles and be very disagreeable to traffic. The oil should be uniformly distributed, and several light treatments are better than a single heavy application of an equal amount.

The material ordinarily used is a light oil that may be applied cold. Paraffin oils are not so desirable as semi-asphaltic products. A 40 per cent to 60 per cent asphaltic oil is probably best for this purpose, especially for initial treatments. Later applications may be made with a heavier oil to good advantage. The use of the heavier material for first treatment would not permit of obtaining the desired depth of penetration, but would form a surface mat which would easily cut through and be very unsatisfactory.

The cost of applying the oil is about 1 cent to 2 cents per gallon. An oil conforming to the following specifications will probably be found to give satisfactory results with proper manipulation.

Specifications No. 1*

Light Oils for Surface Treatment of Earth Roads

(Cold Application)

1. The oil shall be a fluid product free from water.

2. *Specific Gravity.*—Its specific gravity at 25° C. (77° F.) shall not be less than 0.910.

3. *Total Bitumen.*—It shall be soluble in chemically pure cold carbon disulphide to the extent of at least 99.5 per cent.

4. *Naphtha Insoluble Bitumen.*—Of the total bitumen, not less than 1.5 shall be insoluble in 36° B. paraffin naphtha at air temperature.

5. *Fixed Carbon.*—The fixed carbon shall not be less than 2.5 per cent.

6. *Viscosity.*—When 240 cc. of the oil are heated in an Engler Viscosimeter to 50° C. (122° F.) and maintained at this temperature for five minutes, the first 50 cc. which flow through

*Bulletin No. 6, *Dust Prevention*, by Frank L. Roman, Testing Engineer, Illinois Highway Department.

the aperture shall show a specific viscosity of not less than 5 nor more than 15.

7. *Loss on Evaporation.*—When 20 grams of the oil (in a tin dish 2½ inches in diameter and ¾ inch deep with vertical sides) are maintained at a temperature of 163° C. (325° F.) for five hours in a N. Y. Testing Laboratory oven, the loss shall not exceed 25 per cent by weight.

Treatment for Gravel and Macadam Roads

With the advent of motor vehicles, the wear on gravel and macadam roads has become so excessive that the life of this type of pavement is considerably shortened, and it has become a practical necessity to provide some kind of bituminous surface treatment to resist the dusting up and blowing away of the finer surface materials.

There is a considerable difference of opinion among engineers as to the value of a surface treatment for gravel roads. Some roads which have received such treatments have shown satisfactory results, while others given apparently the same treatment have not been successful. As a maintenance proposition, to prevent the dusting up of a road by auto traffic and the wasting of the finer materials by wind and rain, there can be no question as to the economy of such a treatment. The large mileage of gravel roads which have received either hot or cold asphalt and tar surface treatments in Texas during the past two or three years will do much toward proving or disproving the permanence of this type of road construction.

With macadam roads, the case is different. The experience both here and in the East has been that an application of a suitable bituminous material to a well prepared macadam road surface will yield a mat that should last for several years. Here, as in the case of the gravel road, the results obtained depend both on the kind of material used and on a proper attention to detail in its application.

The preparation of the street surface, whether gravel or macadam, is of prime importance. A depression or irregularity left in the street surface at this time will be hard to remedy after the bitumen is applied. Not only must the surface be

brought to the proper cross-section, but it should be thoroughly compacted, either by the use of a steam roller, or by traffic. After being properly bonded together in this manner, all irregularities and depressions that occur should be remedied, and the entire surface brought to a true grade. Any depressions left will hold water, after rains or sprinkling of the pavement, and will be a detriment to the bituminous mat. The street should then be swept clean. It is better if the sweeping even removes some of the binder from the surface material, leaving the individual pebbles or particles of stone sticking up in such a way that the bitumen will have a better opportunity of obtaining a satisfactory bond. These pebbles projecting in this manner appreciably increase the surface exposed to contact with the bitumen, which obviously increases the tenacity with which the bituminous mat will adhere to the road surface. This cleaning of the surface must be thoroughly and carefully done, as upon it depends the bond of the surface mat to the road. Bitumen, whether cold or hot, can not stick to stones or pebbles which are covered with dust, since it can not come into intimate contact with their surfaces.

After the preparation of the street surface is complete, the bitumen may be applied, either by hand pouring pots or by pressure distributors. If the former method is used, it requires very great care to obtain a uniform application of the material. Perhaps the best method is for the man with the pouring pot to walk backward at a uniform rate, allowing the material to flow out on to the street surface without any swinging of the pot. It is much better, however, if the size of the job will permit, to apply the bitumen, whether hot or cold, with a pressure distributor, as a more uniform treatment can be secured by this means. Care should be taken to avoid an overlapping of treated surfaces at successive passages of the distributor, as "fat" places will be formed, which are objectionable.

The amount of bitumen to be used varies from 1/4 to 1/2 gallon per square yard, depending upon the amount that the street surface will absorb. Where the heavier treatment is used, it is preferably applied in two equal treatments. After the bitumen is applied, enough coarse sand or screenings, from

which the dust has been removed, is spread upon the street to absorb any surplus material which the roadway will not. Ample time should elapse before the sanding of the street to allow the bitumen to obtain a maximum penetration into the material of the roadway.

There has been considerable difference in practice as to the kind of material to use in this surface treatment. For first treatment, the heavier materials seem to give very satisfactory results. These materials are usually applied at a temperature of from 250° to 350° F. Some engineers, however, claim that they obtain better results with cold oils, which includes all asphaltic materials having a specific gravity of about 0.98 or less. Asphalt oils having a specific gravity as low as 0.95 may require heating if used in cold weather. For a tar, for cold application, the maximum specific gravity is about 1.22. In either case, for initial treatment, the cover material should preferably be of an amount sufficient to build up a mat from ¼ inch to ⅜ inch in thickness. A coarse clean sand is desirable, while a good grade of stone screenings, with the dust screened out, probably gives better results. Very often, however, the fine material which has been swept from the road is used for this purpose. Unless too large a per cent of loam is present, fairly satisfactory results may be obtained, though not so good as with the coarser materials. The advantage of the coarse material lies in its wearing qualities and greater stability, while the only points that can be urged for the finer material are its cheapness and the increased surface area which it presents to the bitumen for adhesion. This last item probably explains the good results sometimes obtained by the use of finer materials, as against the generally accepted preference for the coarser cover materials. Colloidal chemistry has not until quite recently received the attention and study that it undoubtedly deserves. A given liquid has a certain amount of surface energy, which is the energy exerted by a contact of the liquid film with a solid surface. One gram of sand of such a size as just to pass the 10 mesh sieve would have a surface area of 15 square centimeters, while the same amount of sand fine enough just to pass a 200 mesh sieve would have a surface

area of 283 square centimeters. It is upon this surface tension between liquid films and this increased surface area of extremely fine particles that the theory of the sheet asphalt pavement is based. Mr. Clifford Richardson gives an able discussion of this subject in a recent paper delivered before the Western Society of Engineers.

For retreatment of street surfaces, however, the engineer is confronted by a somewhat different problem. Here the light oils are probably preferable. Where the street to be treated already has more or less of a mat on the surface from previous treatments, the function of the retreatment is not to build up an additional thickness of this mat, but to give new life to the bitumen in the old surface. The lighter oils flux the old material perhaps better than those which are heavier. It is doubtless better, also, to use less cover material in retreatment of surfaces than in initial treatments, for the two reasons above set forth.

It should be remembered that a surface treatment gives a mat which is not of itself stable. It is necessary, therefore, that this mat be not permitted to become thicker than about ½ inch, as it is likely to push and roll under traffic. This will influence the choice of oil to be used, whether heavy or light, and the amount of cover material to be applied.

The following specifications are representative of the asphaltic oils used in this work, both for the cold and for the hot treatment.

Specifications No. 2*

Medium Oil for Surface Treatment of Bituminous or Water-bound Macadam

(Should be applied hot when air temperature is below 80° F.)

1. The oil shall be a viscous fluid product, free from water.

2. *Specific Gravity.*—Its specific gravity at 25° C. (77° F.) shall not be less than 0.950.

3. *Total Bitumen.*—It shall be soluble in chemically pure cold carbon disulphide to the extent of at least 99.5 per cent.

*Bulletin No. 6, Illinois Highway Department.

4. *Naphtha Insoluble Bitumen.*—Of the total bitumen, not less than 5 nor more than 20 per cent shall be insoluble in 86° B. paraffin naphtha at air temperature.

5. *Fixed Carbon.*—The fixed carbon shall not be less than 4.0 nor more than 12.0 per cent.

6. *Viscosity.*—When 240 cc. of the oil are heated in an Engler Viscosimeter to 50° C. (122° F.) and maintained at this temperature for 5 minutes, the first 50 cc. which flow through the aperture shall show a specific viscosity of not less than 30 nor more than 70.

7. *Loss on Evaporation.*—When 20 grams of the oil (in a tin dish 2½ inches in diameter and ¾ inch deep with vertical sides) are maintained at a temperature of 163° C. (325° F.) for 5 hours in a N. Y. Testing Laboratory oven, the loss shall not exceed 25 per cent by weight.

8. *Flash Point.*—The flash point of the oil by the open cup method should not be less than 100° C. (212° F.).

Another debatable question here encountered is whether an asphaltic or semi-asphaltic oil or a tar is preferable. Refined tars such as are used in road work are made from a blending of tars obtained from many different sources and having a wide range of individual characteristics. The two main classifications of tars are water-gas tars and coal tars, the latter furnishing perhaps the bulk of the refined tar used in road construction. These two classes differ considerably in chemical and physical characteristics, and the individual groups making up these main classes also differ considerably. This variation is due to variations in process of manufacturing products of which the tars are by-products. Water-gas tars are not used for road purposes without mixing with some other bitumen. It is apparent, from the wide variety of materials used, that the manufacturer of a refined tar has many difficulties to overcome in producing a uniform product. It seems necessary, therefore, that the specifications for tar products should be very carefully drawn, and the materials as carefully tested, to insure obtaining the material specified. "The points generally covered in specifications are the specific gravity, viscosity or melting point, free carbon, and distillation. With distillation, it is also customary

in the best specifications to report the specific gravity of the distillate and the melting point of the remaining pitch. Some specifications also cover ash, the per cent of naphthaline, and freedom from water. The latter point is covered under distillation, and is superfluous. The ash is of minor importance. It is perhaps well to specify a maximum, to discourage attempts at adulteration. The specific gravity is of importance, as it shows to a certain extent the origin of the crude tars. It should not, however, be confused with viscosity, as the specific gravity and viscosity are only related when the tar serving as a base is the same in both cases.

"The viscosity or melting point is a very important point in refined tars, and must be very carefully specified. It has nothing to do with the origin or composition of the tar, since any tar may be brought to a given viscosity or melting point above certain lower limits. Free carbon has caused more discussion than any other item in the specifications. A large number of experiments carried on to determine this point (the effect of the amount of free carbon in the tar) have seemed to indicate that tars very low in free carbon are too much affected by temperature changes, and also are more subject to change under atmospheric influences than tars which contained a fair amount of free carbon."* Experience has borne out the results as shown by these experiments, and also seems to indicate that a certain percentage of free carbon enhances the binding value of the tar. From 12 to 25 per cent for a binder and from 10 to 22 per cent for a tar to be used in hot blankets are the limits of free carbon allowable. This amount should be reduced to about 4 per cent for materials used in cold applications, as a large amount of free carbon reduces the penetration.

The distillation limits are usually from 170° C. to 300° C. One of the principal advantages of tar over asphalt is that it appears to penetrate more readily into the road surface. This appears to be due to the fact that the viscosity of tar increases much more rapidly with a given rise in temperature than with

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***Chemistry, Manufacture, Transportation, and Control Testing of Refined Coal Tars*, by Philip P. Sharples, Barrett Manufacturing Company, N. Y.

asphalt. For the same reason, tar may be more brittle in cold weather.

Some of the disadvantages are that it oxidizes under climatic influences more readily, and loses some of the more volatile fractions, which causes tar to lose its life more rapidly than asphalt, and for this reason requires treatment at more frequent intervals than the latter. It is more susceptible to changes of temperature, as above indicated, which is another disadvantage, and is injured more by overheating than are the asphalts.

For these reasons, if equal in first cost, an asphalt material is probably more satisfactory than a refined tar, and Eastern engineers are showing a preference for the asphaltic materials.

The following specifications represent the best practice in the use of tar for hot and cold applications.

Specifications No. 3

Refined Tars for Use in Road Blanket Treatments

Specific Gravity: Not less than 1.19 at 60° F.

Viscosity: Engler, 100 cc. at 100° C., 125 to 200 seconds.

Or float test at 50° C., 35 to 60 seconds; or, at 32° C., not less than 2 nor more than 3 minutes.

Distillation: Method of American Society for Testing Materials. Nothing below 170° C., nor more than 24 per cent below 300° C.

Specific gravity of the tar distillate to be not less than 1.03 at 25° C.; residue from the distillation to be 75° C. (cube method in water).

Free Carbon: Not less than 10 per cent nor more than 20 per cent.

Specifications No. 4

Refined Tars Used in Cold Surface Treatments

Specific Gravity: Not less than 1.14 nor more than 1.18 at 15.5° C.

Viscosity: By Engler Viscosimeter, not less than 150 nor more than 300 seconds, for 100 cc. at 40° C.

Distillation: Method of American Society for Testing Ma-

terials, not more than 5 per cent below 170° C., nor more than 32 per cent below 300° C.

Specific gravity of the entire distillate shall not be less than 1.01 at 25° C.; residue from the distillation to have a melting point not greater than 70° C. (cube method in water).

Free Carbon: Not less than 4 per cent nor more than 12 per cent.

The usual method for obtaining the desired penetration with the heavier materials is to heat them until they are liquid enough to penetrate the road surface. When cooling, they harden again to their former consistency.

Another method has been used to some extent, with apparently good success; that is, to "cut back" the bitumen with a light volatile oil to the desired consistency for penetration purposes. The material is then applied, and the flux rapidly evaporates, and leaves the bitumen in the road. The flux is usually a naphtha or gasoline, and is easily mixed with the heavier base in the tank car by filling the tank with the desired amount of each and then pumping out at the top and in through a connection at the bottom until the materials are thoroughly mixed.

Usually about 35 to 40 per cent of flux is used. The following specifications represent the average practice.

Specifications*

Flux:

Beaume gravity, 58 to 60.
Flash, 35° F. (minimum) open cup.
End points of distillation 350° F.

Base:

Specific gravity, 77° F., 1.02 (minimum).
Penetration, 100 grams for 5 sec., at 77° F., 85 to 100.
Loss, 50 grams, 5 hrs., 325° F., not more than 3 per cent.
Soluble in carbon bisulphide, not less than 99 per cent.
Soluble in carbon tetrachloride, not less than 98½ per cent.
Ductility (Dow Method), at 77° F., not less than 45 cm.

*Headley Good Roads Company, Philadelphia, Pa.

The cut-back asphalt made from the combination of the above two products shall conform to the following tests:

Specific gravity, .900 (minimum).

Loss, 20 grams, 5 hrs., at 325° F., 35 to 40.

Penetration of residue, after heating for 5 hrs., 325° F., from 35 to 45.

Viscosity, 50 cc., at 77° F., in Engler Viscosimeter, 275 to 350.

The distillate off below 300° F. shall show a gravity of 53 to 60 sec.

Ductility of residue (Dow Method), not less than 30 cm.

Emulsions are made of bituminous materials by mixing with water, and are used in a similar way as the "cut-back." These mixtures are made either mechanically, which gives a very unstable mixture that must be used immediately, or by adding a small amount of alkali and cheap soap or saponifying material. This emulsion can then be readily mixed with water in any proportions. These materials have not been used extensively, and appear better suited to drives having only light pleasure traffic, as on park ways, etc.

Surface Treatment of Concrete Pavements

Bituminous surfacing or protecting coats have been used rather extensively in California on concrete pavements, and several patented pavements make use of this type of surface treatment. The principal reasons for its use are to do away with the glare of the concrete, to give a better footing to horses, to make a more resilient surface, and to prevent dusting and wear of the concrete. The conditions, both as to climate and as to materials, have been ideal in California, where this type of construction has been successful. Elsewhere, less enthusiasm is felt for this bituminous paint coat. In its application, about ¼ gallon per square yard is used, and covered with screenings or sand, as for gravel and macadam roads. The concrete surface shall be broomed until absolutely clean and free from dust and laitance. It is better to open the street to traffic for several weeks previous to treatment, in order to remove all laitance from the surface. Many failures have arisen from applying the bitumen

too soon. The oil used in California is an oil containing 90 per cent asphalt of 80 penetration.

The two physical requirements of greatest importance are that the oil must have a viscosity such that it can be easily applied and will allow the penetration of the stone screenings, and must be sticky, so that it will bind strongly to the concrete base and bond together the individual particles of the stone screenings forming the mat.

When properly applied, it appears that good results may be obtained. Up to the present time, however, as has been above stated, the experience outside California has not been all that could be desired.

PENETRATION BITUMINOUS PAVEMENTS

By R. G. Tyler, Adjunct Professor of Highway and Sanitary Engineering, University of Texas

[*Synopsis:* Tendency to use cheap labor on this pavement the cause of frequent failures. The success of this surface dependent to a great extent on attention to details in construction. Use of a single size of stone in preference to a well graded aggregate advocated. Cold patching methods described. Longevity of road surface dependent on keeping the surface mat intact. Tendency now to abandon guarantee and insist on carrying out of specifications, leaving the maintenance to the city forces.]

So many errors have been made in the construction of penetration bituminous pavements, and so many failures have resulted therefrom, that some engineers have become convinced that a satisfactory pavement can not be constructed in this manner; and, until the principles involved are thoroughly understood, failures will continue to result. Just because this pavement can be laid without the expensive plant needed for the mixed method of construction, it does not follow that any foreman who can handle laborers can lay a penetration pavement. Even more care is necessary in respect to the various details of construction with this pavement than with some other types. It is a fatal mistake to attempt any paving construction, except under the supervision of a competent engineer.

There are so many things to be said in favor of this type of construction that it is to be hoped that it will receive proper consideration from the engineers who contemplate street improvements. Especially is this true for the smaller towns. Contractors will bid on smaller contracts, since there is no expensive plant required. The unit cost of the pavement is less than for mixed pavements, in the majority of cases. Patch work can be done by the municipality more satisfactorily, and there is no very good reason why the community should not build its own pavements in the first place.

The object of this paper is not to tell something new and startling, but to review the best practice in penetration work,

and to call attention to some of the more important details, based upon work which has come under the speaker's experience and observation.

The same care must be given to securing a proper foundation as is done for other pavements. The base course may be either macadam, gravel, or concrete. The first two are, of course, cheaper; and, since penetration macadam is used in order to secure a cheaper pavement, a macadam or gravel base is the logical one to be used.

The customary thickness of this base is from 4 inches to 6 inches. The thicker courses are usually laid in two layers, to facilitate rolling. Certain precautions need be observed in this operation. The material should never be dumped in rows from dump wagons and then spread with a grader or drag. Roads so constructed are quite sure to be wavy and uneven. When the material is dumped in this fashion, the finer stone works to the bottom of the pile, and, in spreading, only the larger sizes of stone are carried to the outer edges of the roadway. The materials will not compress evenly under the roller, and an uneven surface results. The better plan is to dump on boards, and spread on to the roadway with shovels, or to use certain types of wagons by which the materials may be spread quite uniformly in dumping. If the stone must be dumped in windrows, it should, at least, be harrowed when spread.

The base should be filled with a finer material, which keeps the foundation material from working up into the base, or the bituminous binder from the top course from penetrating down into it and being wasted. Any inequalities of surface are also remedied with this material, and the base brought to the desired crown and grade. A road gravel may be used for this purpose, if cheaper than stone screenings.

This base may be constructed of a softer and cheaper grade of stone than for the wearing surface. It is often possible to use a local material for this purpose, but, the poorer the material, the thicker should be the course.

In constructing the wearing surface, a hard and tough stone is desirable. The course is laid in the same manner as the base course, and usually is from 2 inches to 3 inches thick. It is

necessary that the stone be absolutely clean and free from dust, and dry, so that the bitumen will stick to it. For a 2-inch top, stone from 1½ inches to 2½ inches is the most desirable size. Stone passing a 2½-inch screen will roll down satisfactorily in a 2-inch top course. The size of the stone depends somewhat on the hardness. It should all be nearly the same size, in order to leave this course open to receive the binder. The stone should then be rolled as long as the character of the stone will permit. An experienced roller-man will be able to detect when the stones begin to crush and wear on each other, when it has been rolled sufficiently. The softer materials can not be rolled very much, as the voids will be closed and the surface will go together too much to permit of the proper penetration of the bitumen. If the proper size stone is used for this course and it is well rolled, much will be added to the stability of the pavement by the proper interlocking of the stone. A penetration pavement depends upon this interlocking of the stone in the wearing surface, to prevent rolling and pushing under traffic, quite as much as upon the binding together by the bitumen.

The next step in the process of construction is the application of the binder. This is an asphalt or tar of suitable consistency and characteristics, which is applied hot, either by hand or from pressure distributors. If the wearing surface has been properly laid, it will take up from 1½ gallons to 1¾ gallons per square yard of road surface. This application should be very carefully applied, so as to obtain uniformity of treatment, or fat spots will result. Follow up the treatment with a thinly spread layer of stone, passing the ½-inch or ¾-inch screens, with the dust screened out, and roll this well into the wearing surface. After rolling, the surface is swept free of all dust and loose material, and a seal coat of ¼ gallon per square yard applied. This is followed by a coat of cover material of stone screenings, and rolled, if desired. This cover material is worked into the voids between the surface stones, and a smooth and compact surface results. If on hillside work, the seal coat may be left off, so as to form a rough surface. A pavement of this type will improve after it has been down a short time and the binder has worked up to the surface and formed a mat.

In practice, the plant necessary for laying this type of pavement is very inelaborate. The bitumen may be heated in portable kettles, taking care not to allow the temperature to approach the burning point. Three hundred and fifty degrees Fahrenheit is the maximum temperature that should be allowed. If there is water in the bitumen, it will have to be heated gradually and the temperature raised slowly, to prevent foaming. The material can then be applied by hand or from pressure distributors. While the latter is preferable, the former gives satisfactory results, with proper care.

A pouring pot having a broad spout should be used, the operator walking backward, without swinging the pot from side to side. The uniformity of the pavement surface depends very much on the uniformity of this treatment. A 10-ton steam roller and a few teams for hauling complete the plant equipment. With this simple plant a city may easily and economically build its own pavements.

The tendency now is to break away from the practice of having a pavement built under a five-year guarantee. Engineers are finding it cheaper and more satisfactory to specify what they want in a pavement, to have their inspectors see to it that the specifications are lived up to, and to maintain the pavement with city forces. Not only is this method cheaper, but the pavement may be kept in good condition at all times, and cuts made by public service corporations repaired without delay. Here the penetration pavement is particularly advantageous, as small repairs may be done economically by a municipal repair squad.

Considerable repairing of penetration pavements has been done in the East by cold mixtures. About 18 to 20 gallons of the asphalt oil or tar are added to a cubic yard of graded aggregate. The whole is thoroughly mixed, the hole to be patched cleaned out, painted and filled, and the patching material patted down with a shovel, leaving it a very little higher than the surrounding pavement, to allow it to pack under traffic. These patches may be mixed on the job in the desired amounts, and should prove inexpensive. It is not usually considered good practice to use a different kind of material on patchwork than in the original construction.

In all types of bituminous pavements, it is necessary to keep a thin surface mat of bitumen and sand or screenings covering the pavement proper. This, in the speaker's opinion, is the secret of longevity of a pavement. When this mat wears off, the mosaic appearance so familiar to us all is in evidence. The stone begins to wear, and the wearing course becomes thinner. This should never be permitted. The wearing course would wear entirely away in a few years, and have to be replaced at considerable expense, while a fresh flush coat can be applied every few years, as it may be needed, at a cost of only a few cents per square yard.

We read of pavements in the East that have been down forty years, and upon investigation we find that, as soon as the stone begins to show up, as above stated, the street received a paint coat of bitumen and cover material, which took the wear until the stone again began to appear, when the treatment was repeated. There seems to be no good reason why the life of a pavement, whether penetration or mixed, should not be prolonged indefinitely in this manner. We would not think of letting the top course wear away and expose the base course to traffic, so why should we let the thin surface mat wear away and expose the top course to wear? In the speaker's opinion, this bituminous mat is just as important a part of the pavement as either the top or base courses.

One cause of ravelling of penetration pavements is the splintering of the fragments of stone by blows from the caulks on the horses' shoes. These fragments pick out, and a hole is the result. If a large per cent of the traffic is motor driven, it may be able to keep these places ironed out, but the trouble will probably not occur if the surface mat is intact.

The penetration road is a satisfactory road when properly constructed. It should have a wide field of usefulness in streets not having extremely heavy traffic, and should become a popular type of construction for highways outside our municipalities. Undoubtedly it is destined to come more and more into use in county and state highway construction, as has been the case elsewhere; and this will be fortunate, since this pavement is cheap, durable, and suitable for all kinds of vehicles which may be used thereon.

A DISCUSSION OF ROAD MATERIALS

By J. P. Nash, Testing Engineer, Bureau of Economic Geology and Technology, University of Texas

Synopsis: A brief discussion on the type of road suitable for the traffic to be carried, considering each type of road material separately as to its necessary properties. Includes a discussion of sand-clay, gravel, crushed-stone macadam, concrete, brick, rock-asphalt, and shell, with a plea for more favorable railroad rates on road-building materials.]

It has been variously estimated that from twelve to twenty million dollars was spent during the past year for road work in this state, and it has also been prophesied that there will be as much as thirty million spent during the current year. As the greater percentage of this money is spent for new construction and re-surfacing old construction, it is very essential that the road material used be the best obtainable. With the lower types of construction, such as the sand-clay or gravel roads, the proportion of the money spent in building the road will be about 40 per cent of the total amount. As the higher types of road construction are approached, such as the water-bound bituminous macadam, the materials represent a still larger percentage of the total cost, perhaps 60 per cent. Still higher in the scale of road construction, such as the concrete, brick, or asphaltic concrete road, the material cost will range somewhere between 60 and 70 per cent of the improvement.

The necessity for using the best materials that can be found in a locality, as can readily be seen, is absolutely essential, if the taxpayers are to receive full value for the money they give for these improvements. If, by the use of a better material, it is possible to give the road one more year of life, it certainly is a paying proposition to investigate completely the whereabouts and the value of each road material in that locality. This is the method of doing business that all large and successful corporations use. They must see to it that they are to receive full return for the money, before capital will be extended for the project.

If road building were carried on under a system similar to that used by these corporations, there would be fewer sand-clay and gravel roads built for modern traffic from twenty-year to forty-year bond issues, as is now a daily occurrence. Self-protection would dictate this.

The state laws of New Jersey recognize this fact when they require that the bond issue shall be limited in time according to the type of road and the materials used. Five years is the limit which a bond issue may run, if the type of road to be constructed is gravel; ten years, if macadam, and twenty years, if concrete, brick, or bitulithic. And it should be noted, further, that the gravel roads of New Jersey are constructed much better than those of our state; in fact, the gravel roads of New Jersey are noted in this country for their general satisfaction.

It is very hard to understand why a commissioners' court will construct a sand-clay or gravel road for the heaviest traffic highways, when it knows before building the road that as much as 80 per cent of the traffic will be motor-drawn vehicles. This type of construction passed away with the advent of the automobile. It is a notable thing when we consider how the methods of transportation have changed in the last century, and yet the average road built today in Texas has little improvement on those built a hundred years ago. It should not be inferred that sand, clay, or gravel roads are not a satisfactory type of construction, but they are not satisfactory or economical from the standpoint of modern traffic. If, for any reason, one should doubt the type of traffic which a road must stand, it would pay him to spend a day or two each month in taking a traffic census of a few of the main traveled roads, and I feel sure he will agree that the greatest proportion of this traffic consists of motor-drawn vehicles.

The proper type of road is one that will suit the traffic. This means that the materials used must not only be the best that can be had, but must also be of a type which will withstand the traffic that the road must carry. These two facts are of equal importance, and both deserve considerable attention. It is well, however, briefly to outline what is the best material of

each class, and leave it to the traffic on the individual road to determine what class should be put in. This class distinction might roughly be decided by noting whether the road carries mostly steel-tired vehicles or motor-driven vehicles. Modification of these classes lies also in the number and weight of the vehicles; that is, roughly, in whether the road is a through highway or merely a secondary road.

To pass on to the best grade of materials for the different classes: First, the earth road should be considered, but it is unnecessary to dwell upon that, for the reason that construction of the earth road lies only in such matters as drainage, alignment, and grade.

The sand-clay road, however, deserves some attention. To make a successful sand-clay road, it is essential that both the sand and clay have properties which are suitable for the purpose. The clay must be one having good binding qualities,—also one that will remain intact and not break down into mud as soon as it comes in contact with water. Usually, it is the poorer binding clays that slack easily. The duty of the clay is to bind the particles of sand together in a compact mass that will remain intact through dry spells. A red iron-oxide clay is very satisfactory. The sand should be rather coarse grained, and, if possible, well graded. The failure of most sand-clay roads can be laid to poor sand rather than to the clay. A fine sand is not satisfactory, for the reason that when the road is wet such a fine sand fails to do the work which it is supposed to do; namely, that of supporting the traffic during the wet spells. There are many so-called gravel roads built which are really sand-clay roads, as pebbles making up these gravels are possibly only ½-inch or ⅜-inch in size. Such gravels are recommended by the laboratory only as sand-clays, and should not be expected to give service such as is obtained from a real gravel road, except perhaps as a binder course.

The question of the amount of clay and sand which presents the best road surface is one of importance, but no set rule can be laid down for these proportions, as this is a matter of trial. There should be, however, enough clay mixed with the sand to bind the grains together, and this will usually be from 20 to 35

per cent of the sand. A sand-clay road is, perhaps, one of the most difficult of roads to construct, in that it takes constant care in building, and should be maintained for many months after the road is virtually completed, as weak spots invariably develop.

Such a type of road is only satisfactory for a medium horse-drawn traffic, and, even if this kind of traffic is considerable in volume, the gravel road would prove more economical and efficient.

This brings up for consideration just what constitutes a good gravel for road construction. Theory and practice agree well upon the qualities that a good gravel should have. In the first place, there should be sufficient quantity of large stone between ⅛ inch and 2 inches in size to support the weight and take the wear of the vehicles. These larger stones, which are invariably rounded, must be held in place by a filler of sand, so that they will be unable to move. Now, the sand and the gravel will make a dense surface, but it is necessary that there be another ingredient to bind these together, and this is the function of the clay. Like that recommended for the sand-clay road, the clay in the gravel should have good cementing qualities.

The coarse pebbles between ⅛ inch and 2 inches in size should constitute from 60 to 70 per cent of the gravel, the sand and clay together to make up the remainder. It has been found that from 12 to 20 per cent of clay is sufficient. It is hard to convince the average citizen that this is a satisfactory gravel, as it has a very lean appearance when placed on the road. After it carries traffic for a few months, it sets up into a much more satisfactory surface than does one which contains a greater proportion of sand and clay. A gravel having these proportions is somewhat difficult to find, as the average gravel contains too much sand and only a small proportion of stone.

The above proportions of clay apply to a gravel in which the stones have no cementing values, such as a flint and quartz gravel. With a limestone gravel, the proportions can be altered. This is due to the fact that the stones are usually softer, and are being continually worn by the traffic. This condition permits the use of a gravel having little fine material, and, in

fact, it is desirable that it have but little. The proportion of sand to stones should be the same; namely, 1 to 2, but it is unnecessary that more than 7 per cent of fine material be present. As with the flint gravels, this, also, will seem to be lacking in fine material, but, after the road is compacted, it will be a superior road. The sand under ⅛-inch should be composed of hard limestone, similar to the coarse pebbles, and should constitute about 30 per cent of the compacted road. In all gravels or sands for road work, it is essential that the pebbles composing them be hard and tough, in order to resist the wear. Toughness is probably more essential than hardness, as the smaller pebbles must resist considerable impact or be ground into dust.

Above everything else, a gravel road is satisfactory only for medium or heavy horse-drawn traffic, but is in no sense suitable for automobile traffic. There are a number of localities in this country where it can be demonstrated that gravel roads for automobile traffic are a sound investment, when well maintained, but none of these localities are in Texas. The climatic, soil, and material conditions must all be exceptionally favorable to make the gravel road economical for heavy motor traffic, but in this state these things are not present to sufficient degree. Gravel roads have been given a satisfactory surface in recent years for motor traffic by treating them with asphaltic oils and tars. As satisfactory as these treatments may have been, there is little doubt that they would even prove more economical on a crushed stone road.

This brings us to another type of road material deserving consideration: crushed stone. This is superior to the gravel in many respects, chief of which are its uniformity and the interlocking action of the stone. It is essential, however, that the stone have qualities to resist the wearing action of traffic. The stone must resist the impact of the horses' hoofs and of steel-tired vehicles, the wearing action of traffic on the road surface, and also the internal friction of the stones one upon another within the body of the road, due to the weight of the vehicles. In other words, the stone must be tough, it must have a high resistance to wear, and it must be hard. Another quality re-

quired of the stone is that it have good binding qualities. This latter feature is becoming less and less important, as practically all stone roads built in this state are bituminous roads. When the old water-bound macadam road was in vogue, this binding property was one of prime importance, as it was the binder that held the stones together and kept the road smooth. This natural stone binder has given way to the more satisfactory artificial binders, the most common of which are the asphalts, oils, and tars.

While bituminous binder in a macadam road reduces to a considerable extent the shock and wearing action of traffic on the stones, there is yet great need of stone which will resist these forces. The ordinary narrow-tired wagon used in this state, with a two-ton load, would mean, a pressure of about 1,000 pounds on each wheel. This would be about 166 pounds per square inch on the road surface, considering that the tire is but 2 inches wide and has about 3 inches of its circumference in contact with the road at one time. Should this vehicle drop as much as ½ inch, due to a depression in the road, there would be enough impact from this blow to break a 1-inch piece of the ordinary limestone found in the state. This weight will also compress the road surface enough to cause slight friction between the stones, thereby wearing them to a certain extent. The impact of the steel-shod horses' hoofs breaks the stones also. With the motor-drawn vehicle, practically all of this impact is eliminated, due to the cushioning effect of the rubber tires. However, there still remains the internal wear due to the weight of the vehicle, and the shearing action of the rear wheels.

It is necessary that the stone have properties to resist these various destructive forces, and these properties can be shown very clearly by tests on the material. Unless a person has had considerable experience in judging these properties in a stone, it is very difficult to determine, without testing, the actual properties of various materials, as the actual figures give an excellent method of comparison.

It has been said by many people that Texas has no suitable stones for road construction, but this is far from the truth. There are limestones in this state which are equal, and in many

cases superior, to those of New York, Pennsylvania, Illinois, or practically any state that might be mentioned where roads are constructed of these materials. There is trap rock found here equal to that of New York, Washington, or Oregon. There are granites in the Burnet and Llano country which are equal to those of Vermont or New Hampshire, Colorado or any other granite-laden state, and there are sandstones in the northeastern section of Texas which are as hard and as tough as any that can be found elsewhere. The real fact of the matter is not that good road building rock is absent, but that it is rather poorly distributed. One of the most important and far-reaching benefits which the State Highway Commission can do for road improvement in this state will be to secure favorable rates for the shipment of these materials for road-building purposes.

The high cost of transporting these materials, coupled with the ignorance of their existence, is the chief reason that they have not been used to a greater extent.

In the construction of a concrete road, the question of satisfactory materials is one of paramount importance, not only in the wearing qualities of the various materials that make up the road, but also in their relative proportions. Whether gravel or crushed stone is the most satisfactory material to use is also a live question. It has been demonstrated in the laboratory, and it is believed that it will hold true in actual construction, that a limestone would present a more uniform surface than gravel after the road has commenced to wear, other things being equal. This statement, however, requires some modification, first in regard to the character of the gravel, and second in regard to the richness of the mortar. The gravel is usually rather ununiform, being composed of both hard and soft pebbles, the softer ones wearing much faster than the hard material, such as flints and quartz, causing the road to become rough. The limestone, being uniform in character, will allow all the stones to wear equally in amount, thereby presenting at all times a smooth surface, which is the one thing desired above everything else to make a satisfactory road. It is believed, also, that the wearing qualities of the mortar should vary with the hardness of the stone. In other words, if a stone having high resistance

to wear is used, the mortar should be rather rich; for instance, about 1 to 1½. This question of the concrete road is a very broad one, and therefore cannot be discussed further at this time.

Passing on to the consideration of the brick road, the question of the materials of this type of construction depends, to be sure, on the quality of the brick. Good brick should have a high resistance to wear and considerable resistance to impact. Besides these qualifications, it is also necessary that they be of such size and weight that they can be handled easily. Various tests are made to determine the wearing qualities of the brick, the most successful of which subject the brick to a real wearing action, such as is done in the rattler test.

There are no country roads constructed of brick in this state, and in most of the towns this type of construction is considered a luxury for only the heaviest traffic streets. This is due to the fact that the traffic is not dense enough to make this an economic form of construction. At the present time, there is but one plant manufacturing paving brick in this state, although there are numerous very satisfactory deposits of clay and shale, which, if properly handled, would make excellent brick for paving.

There are other materials used in highway construction which are used mainly for city streets, and will not be considered in this discussion. However, mention should be made of a natural material which exists in the state, and has recently entered into the sphere of country-road construction. This material is rock-asphalt. The material itself is a soft shell limestone, impregnated with from 8 to 14 per cent of asphalt, the general average being about 11 per cent. There have been a number of miles of city streets built with this material, but recently the method of handling and placing it on a road without the addition of heat has been devised. This material is used as a top course for heavy traffic roads that have a good foundation, or, if such a foundation does not exist, it can be constructed usually with crushed stone or compacted gravel. The necessary precaution in using this rock asphalt is that it must be uniform, and, as the material in nature does not possess this property, it

is necessary that it be supplied to the material, by the addition of some flux or asphaltic oil.

While there are a number of deposits of rock asphalt in the state, there is but one that is worked commercially. The field of economical uses of this material is somewhat limited by the cost of transportation.

Shell as a road-building material is satisfactory for ordinary horse-drawn traffic, but the great clouds of dust which arise from a shell road when a fast moving automobile passes over it spells its doom for modern traffic. There are, however, some qualities which shell must have to be satisfactory for any road, such as a degree of hardness and binding qualities. Lacking either of these qualities, the shell should never be used. The great problem with this type of construction is not so much one of material as it is one of how to treat the road so that it will not blow away, as the shell forms a hard and smooth surface when protected from water and wind.

The above brief discussion of road-building materials might be summed up into one sentence: Use a material suitable for each kind of traffic. The most reliable method of determining the value of the material is by laboratory tests, as a direct comparison with satisfactory roads can be made by means of figures.